Radon Mapping

Santa Barbara and Ventura Counties

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Government agencies throughout the U.S. are looking into ways to evaluate the potential for high levels of indoor radon gas. With the help of ongoing studies and cost effective technology, radon maps are being produced to guide these agencies in their planning and radon mitigation programs. Probably the most important outcome of this work is that more efficient methods are being used to identify areas of potentially high levels of radon. These methods take into account radon's occurrence as associated with a geologic setting, not a homogeneous distribution...*editor*

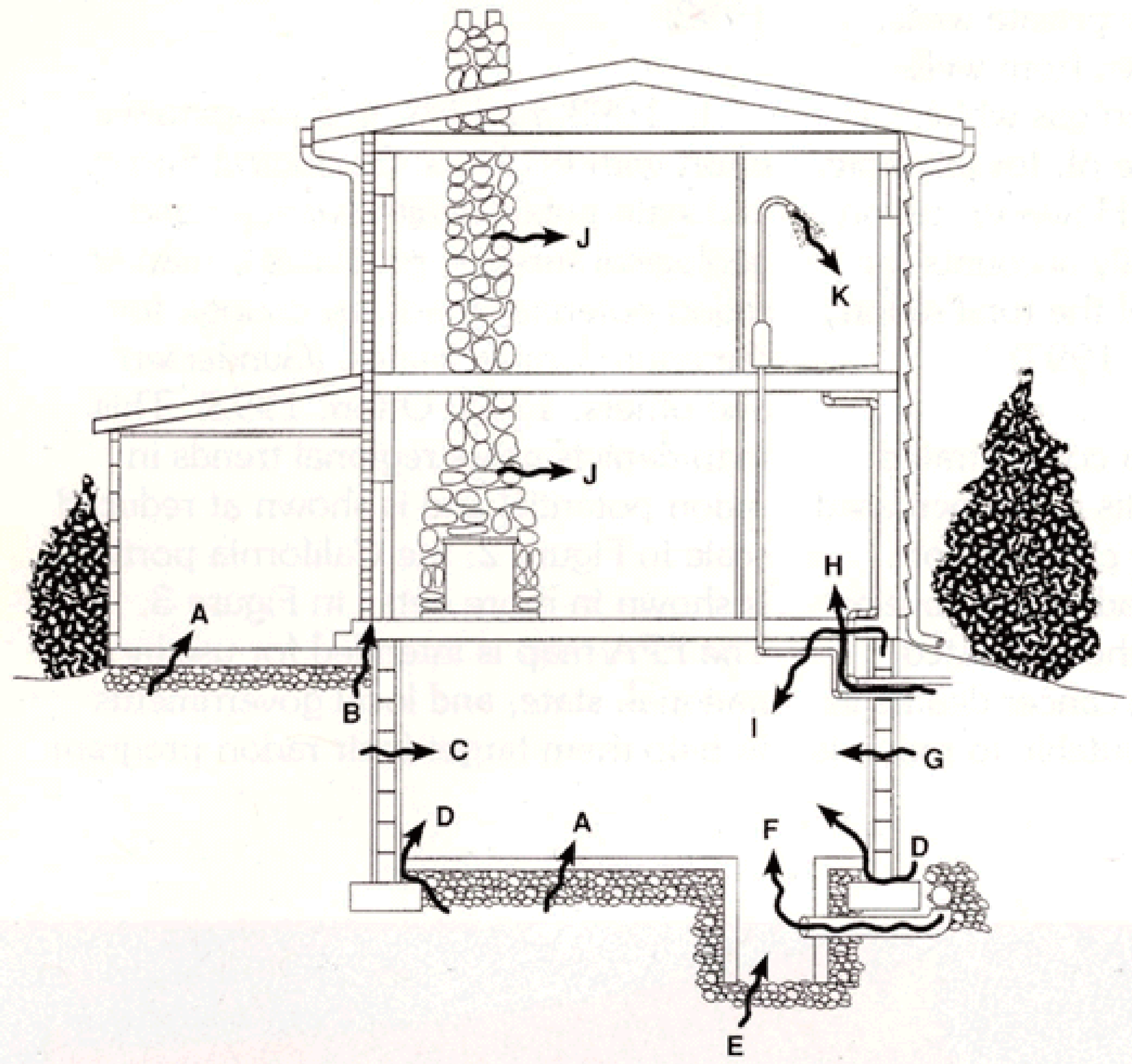

Figure 1. Diagram of cut-away of a house with radon routes. Arrows indicate possible entry points and pathways of radon into a building from the surrounding soil and rock. Source: Environmental Protection Agency (EPA) brochure *Radon Reduction in New Construction, An Interim Guide.*

INTRODUCTION

Since 1990, the Department of Conservation's Division of Mines and Geology (DMG), has provided geologic information and conducted several research projects on geology and **radon*** for the California Department of Health Services (DHS) Radon Program. This article provides a brief overview of radon's occurrence and impact on human health, and summarizes a recent DMG project for DHS that used geologic, geochemical, and indoor radon measurement data to produce detailed radon potential zone maps for Santa Barbara and Ventura counties.

Radon Overview

Radon gas is a naturally-occurring, radioactive gas that is invisible and odorless. It forms from the radioactive decay of small amounts of uranium and thorium naturally present in rocks and soils. Typical concentrations of uranium and thorium for many rocks and soils are on the order of a few parts-per-million (ppm). The average uranium content for the earth's continental crust is about 2.5–2.8 ppm. Certain rock types, such as black shales, some granitic rocks, and rhyolites can have uranium and thorium present at levels of tens to hundreds of ppm. While all buildings have some potential for elevated indoor-radon levels, buildings on rocks and associated soils containing concentrations of uranium or thorium will have a greater likelihood of elevated indoor-radon levels.

Radon gas moves readily through rock and soil along micro-fractures and through pore-spaces between mineral grains. Movement away from its site of origin is typically a few meters to tens of meters, but may be up to several hundred meters. Many conditions affect how far radon can move in the subsurface but the ultimate limitation is the relatively short half-lives of radon's different isotopes (Table 1). Because radon-222 has the longest half-life, it is usually the predominant radon isotope in indoor air.

Radon gas moves from the soil into buildings in various ways. It can move through cracks in slabs or basement walls, pores and cracks in concrete blocks, through-going floor-wall joints, and openings around pipes (Figure 1). Radon moves into buildings from the soil when air pressure inside the buildings is lower than the air pressure out-

Table 1. Half-lives of Naturally Occurring Radon Isotopes.

Isotope	Half-life
radon-218	6 miliseconds
radon-219	3.96 seconds
radon-220	55.6 seconds
radon-222	3.82 days

Source: Heiserman, D.L., 1992, p. 305.

*Terms in **boldface** type are defined in the Glossary on page 176.

side. When exhaust fans are used, or the inside air is heated, or where wind is blowing across the building, the building's internal air pressure is lowered. Because radon enters buildings from the adjacent soil, radon levels are typically highest in basements and ground floor rooms. It can also enter those buildings that use private wells. The ground water drawn from wells contains dissolved radon gas which can be released through use of, for example, the bathroom shower. However, radon from this source typically accounts for only about 5 percent of the total radon in indoor air (WRRTC, 1997).[1]

Breathing air with a concentrated level of radon gas results in an increased risk of developing lung cancer. Not everyone exposed to radon will develop lung cancer, however the estimated annual number of lung cancer deaths in the United States attributable to radon is between 7,000 and 30,000 according to independent estimates by the U.S. Environmental Protection Agency (EPA) and the National Cancer Institute (NCI) [EPA, 1992; EPA 1997]. The average radon concentration for indoor air in American homes is about 1.3 **picocuries** per liter (pCi/L), based on a 1991 national survey (EPA, 1992). The average radon concentration in outdoor air is about 0.4 pCi/L. The EPA recommends that individuals avoid long-term exposures to radon concentrations above 4 pCi/L. Based on long-term radon test statistics, the EPA estimates more than 6 million houses (about 1 out of 15) have radon levels above 4 pCi/L and more than 60,000 homes have radon levels above 20 pCi/L (EPA, 1992).

In 1993 the EPA, in a cooperative effort with the U. S. Geological Survey, and state public health agencies and geological surveys, produced a map of radon potential zones, by county, for the entire United States. (Gundersen and others, 1993; Otton, 1993). This map depicts gross regional trends in radon potential and is shown at reduced scale in Figure 2; the California portion is shown in more detail in Figure 3. The EPA map is intended for use by national, state, and local governments to help them target their radon program activities and resources (EPA, 1993). It is also intended to help building code officials determine areas of highest priority for adopting radon resistant building practices. The map of radon zones, and its accompanying reports, should not be used to determine if individual homes in any given area need to be tested for radon, nor can they be used to predict indoor radon concentrations of individual homes, building sites, or housing tracts. **The EPA recommends that all homes be tested for radon, regardless of their geographic location or zone designation**. It is important to realize *all* map zones contain some homes and buildings with indoor radon levels above the EPA recommended action level of 4.0 pCi/L. EPA has encouraged the states and counties to conduct further research and data collection efforts to refine the radon zone map.

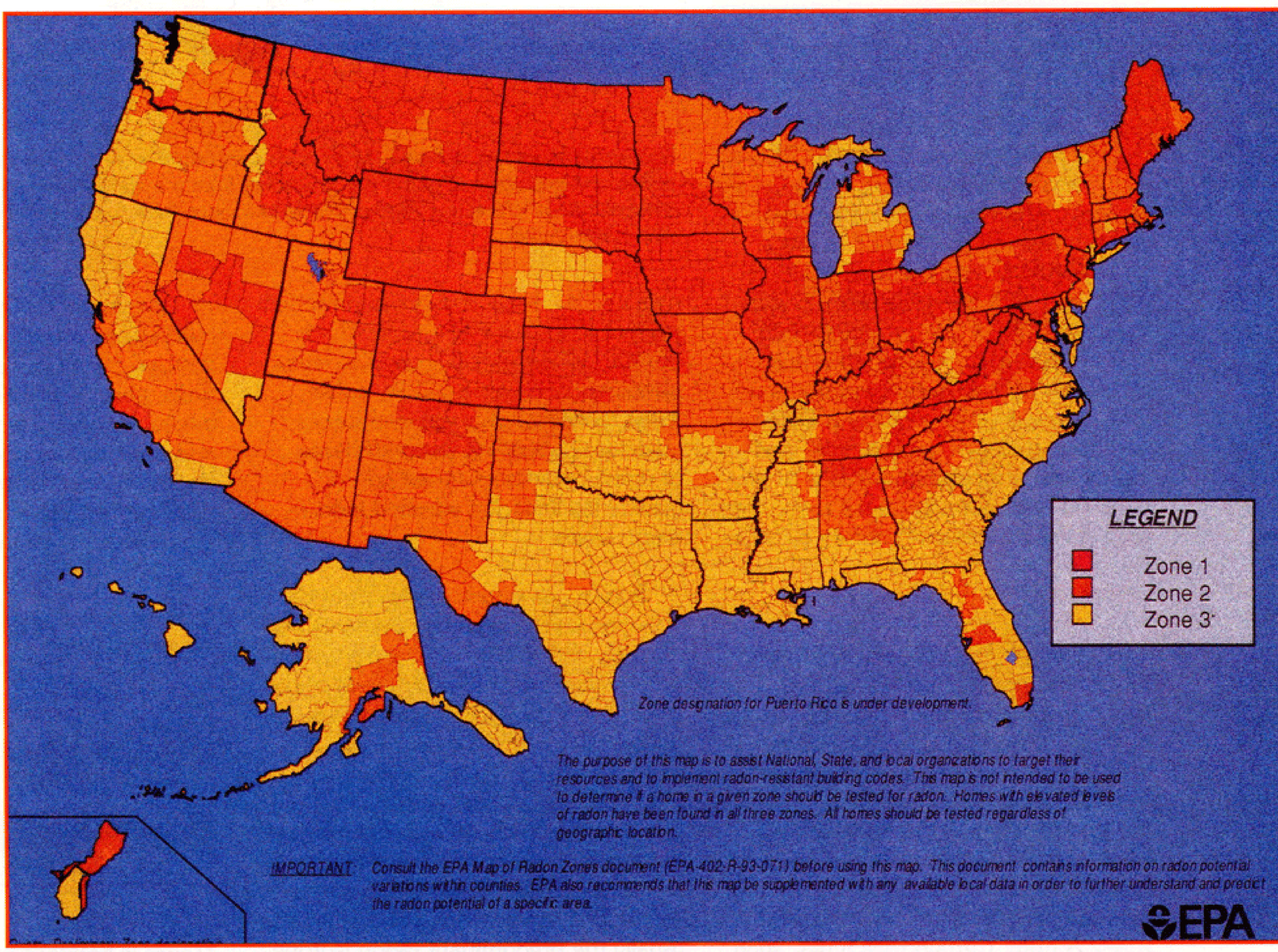

Figure 2. EPA map of radon zones in the United States.

[1]It is estimated that 1 picocurie per liter (1pCi/L) of radon is added to indoor air for every 10,000 pCi/L of radon dissolved in well water, assuming complete release of the dissolved radon into the air.

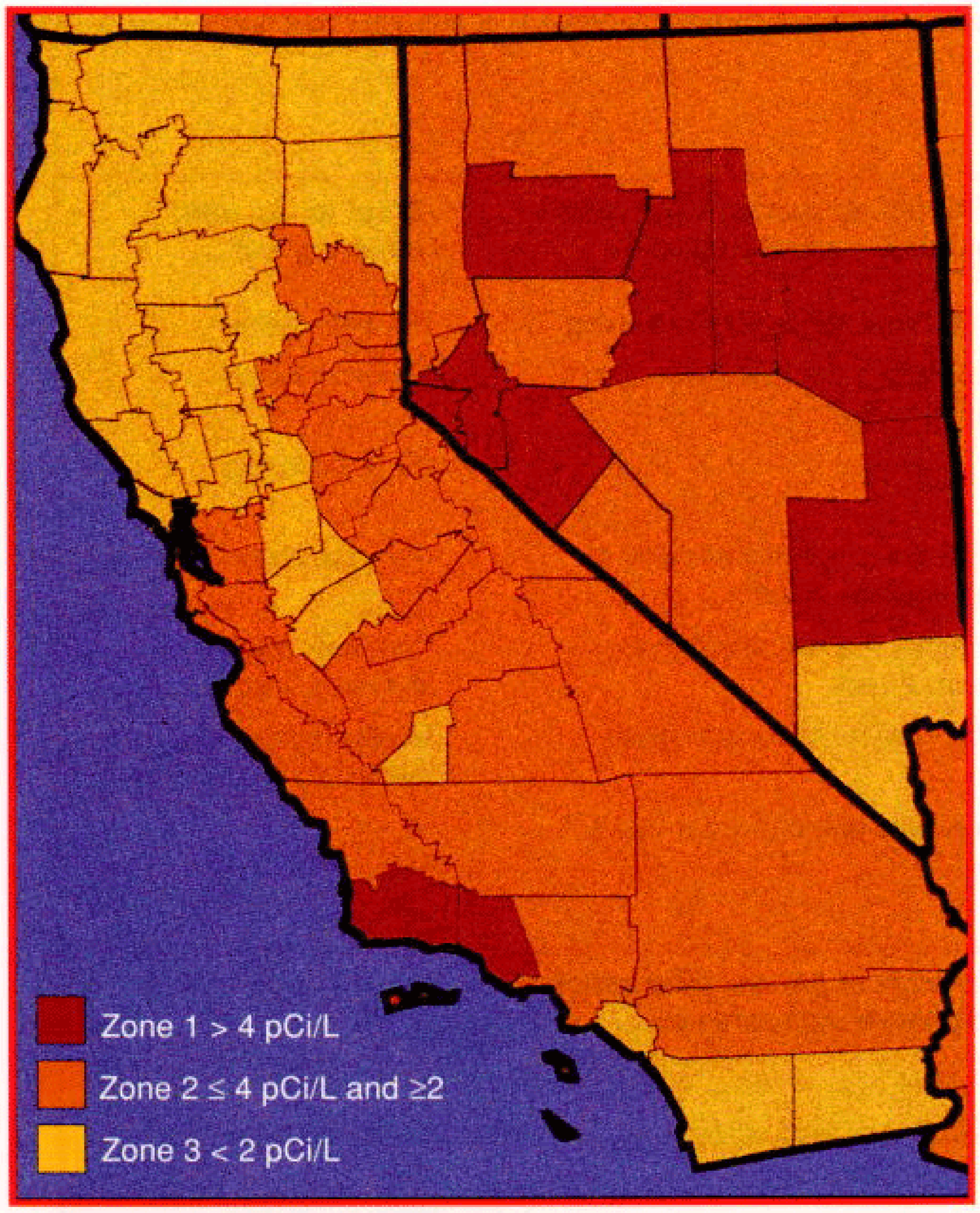

Figure 3. EPA map of radon zones in California shows counties zoned with predicted average indoor screening level.

Radon Exposure Effects and Health Risk Estimates

Although radon levels are used as a guide for acceptable levels of exposure and for action levels, it is primarily the inhalation of two **radon daughter** elements, polonium-218 and polonium-214, that leads to lung cancer. These elements have very short half-lives and when they enter the lungs they attach to lung tissue or to trapped dust particles and undergo radioactive decay. This is in contrast to longer-lived radon-222 that is mostly exhaled before it undergoes radioactive decay. The **alpha-particles** emitted as polonium-218 and polonium-214 decay are thought to cause lung cancer by damaging the DNA (deoxyribonucleic acid) in lung tissue cells, resulting in abnormal or tumorous cell growth (Brookins, 1990).

Current health-risk estimates of exposure to low levels of radon (Figure 4; Tables 2 and 3) are based on extrapolations from high-level radon exposures experienced by uranium miners between the 1940s and the 1960s (Brookins, 1990). This group of miners has a much higher than expected occurrence of lung cancer. Some scientists have questioned whether the relatively low radon levels typically found in residences actually increase the risk of lung cancer. In other words, is it valid to estimate health risks for exposures to low radon levels using health data from miners, many of whom were exposed to much higher radon levels? The World Health Organization and the National Academy of Sciences believe so, and the Center for Disease Control, the Surgeon General, the American Lung Association, and the American Medical Association all agree that current knowledge of the health effects of radon are sufficient to encourage action when indoor air levels exceed 4 pCi/L (EPA, 1997).

Radon in California

DHS has conducted several statewide radon studies to estimate the percentage of California residents exposed to residential radon concentrations exceeding 4.0 pCi/L. The first of these studies, funded by the Air Resources Board, involved 1 year duration alpha-track measurements of 310 randomly selected houses in 1988-1989 (Lui and others, 1990). The results of this test suggested about 0.8 percent (240,000 residents) of California's population was exposed to radon concentrations exceeding 4.0 pCi/L in their homes. Recent work by Hobbs and Maeda (1995), using this DHS radon database, predicts that the average radon levels in 1.9 percent of California homes exceed 4.0 pCi/L.

In their study, Lui and others (1990) examined 60 residential sites in detail and found the best single predictor of indoor radon concentrations was the **emanation** rate of radon from the soil, while other associated parameters were geographic region, building ventilation, type of building substructure, and type and age of residence. Newer single-family residences on concrete slabs with rarely-opened windows and doors were generally found to have higher radon concentrations.

In 1990, DHS joined the EPA's state radon program under the Federal Radon Abatement Act. DHS and EPA jointly conducted a statewide radon survey utilizing 2 to 7 day charcoal canister measurements for 1,885 randomly selected homes in nine geographic regions of California between January and April 1990 (DHS, 1993). These measurements ranged from less than 1.0 pCi/L to 29.1 pCi/L; the measurement statistics are similar to those of the much smaller study by Lui and others (1990) above (DHS, 1993; Otton, 1993). Based on this 1990 short-term data, the EPA estimated that 2.4 percent of the homes statewide would exceed 4.0 pCi/L. Compared to 34 other states that had completed similar testing, California's percentage of homes exceeding 4.0 pCi/L ranked 32. Regions within the state, having highly elevated concentrations of radon were not found during this survey, however excessive levels of radon locally distributed were detected by other surveys.

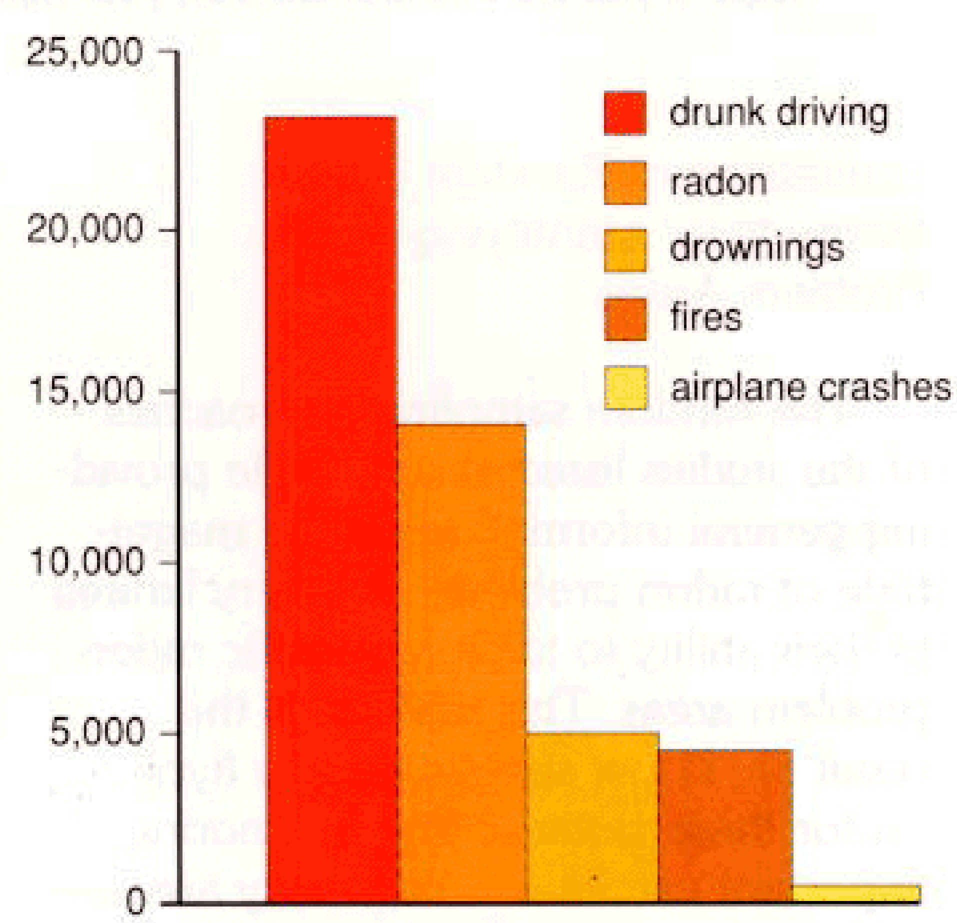

Figure 4. Comparison of estimated deaths by cause per year in the United States. Chart modified from EPA's *A Citizen's Guide to Radon (second edition)* 1992.

Tables 2 and 3 provide an idea of how *lifetime exposure* to various radon levels (70 years, 75 percent of this time spent in indoor-air at a given radon level) compares with other risks.

*Table 2. Radon Risk if You Smoke.**

Radon level	If 1,000 people who smoked were exposed to this level over a lifetime...	The risk of cancer from radon exposure compares to...	What to do: stop smoking and...
20 pCi/L	±135 people could get lung cancer	100 times the risk of drowning	Fix your home
10 pCi/L	±71 people could get lung cancer	100 times the risk of dying in a home fire	Fix your home
8 pCi/L	±57 people could get lung cancer		Fix your home
4 pCi/L	±29 people could get lung cancer	100 times the risk of dying in an airplane crash	Fix your home
2 pCi/L	±15 people could get lung cancer	2 times the risk of dying in a car crash	Consider fixing between 2 and 4 pCi/L
1.3 pCi/L	±9 people could get lung cancer	Average indoor radon level	Reducing radon levels below 2 pCi/L is difficult
0.4 pCi/L	±3 people could get lung cancer	Average outdoor radon level	

*Table 3. Radon Risk If You Have Never Smoked.**

Radon level	If 1,000 people who never smoked were exposed to this level over a lifetime...	The risk of cancer from radon exposure compares to...	What to do...
20 pCi/L	±8 people could get lung cancer	The risk of being killed in a violent crime	Fix your home
10 pCi/L	±4 people could get lung cancer		Fix your home
8 pCi/L	±3 people could get lung cancer	10 times the risk of dying in airplane crash	Fix your home
4 pCi/L	±2 people could get lung cancer	The risk of drowning	Fix your home
2 pCi/L	±1 person could get lung cancer	2 times the risk of dying in a home fire	Consider fixing between 2 and 4 pCi/L
1.3 pCi/L	-1 person could get lung cancer	Average indoor radon level	Reducing radon levels below 2 pCi/L is difficult
0.4 pCi/L	-1 person could get lung cancer	Average outdoor radon level	

*Reference: *A Citizen's Guide to Radon (second edition)* EPA, 1992.
Note: If you are a former smoker, your risk may be higher.

Limitations of Random Survey Methods for Identifying Radon Problem Areas

The random sampling approaches of the studies listed above, while providing general information on the magnitude of radon problems, are very limited in their ability to identify specific radon problem areas. This inability is the result of: 1) low sample density (typical for these studies), and 2) ignoring important variables within study areas—such as the spatial distribution of rock types and soils that are more conducive to causing indoor radon problems. If small radon-prone areas occur in a large area being evaluated by random sampling, they will often be missed unless a very large number of houses are tested. This was a problem in Santa Barbara and Ventura counties where the Rincon Shale (a radon prone geologic unit that accounts for about 1.27 percent [58.4 square miles] of the combined surface area of these counties) was not identified by the EPA and DHS surveys just discussed. However, this unit was identified as a radon concern by Carlisle and Azzouz in 1990 (Azzouz, 1990; Carlisle and Azzouz, 1993) using a "direct exploration" approach to identify radon problem areas.

The direct exploration approach examines available geologic and geochemical data in detail to identify areas and rock units with elevated background uranium levels and, consequently, greater potential to cause indoor radon problems. Areas identified by this process as radon prone can then be field checked by testing the radon levels in associated buildings. Seventy to seventy-five percent of homes on the Rincon Shale exceeded 4.0 pCi/L and 20-25 percent exceeded 20 pCi/L in follow-up short-term testing (see page 175) by DHS. Long-term alpha-track measurements (with normal ventilation) indicate a little more than 50 percent of the houses on the Rincon Shale exceed 4.0 pCi/L (Carlisle and Azzouz, 1993); the highest measurement was 128 pCi/L (Dave Quinton, DHS, oral communication, 1993). In response to these test results, DHS designated the portion of Santa Barbara County from Summerland to Gaviota and south of the crest of the Santa Ynez Mountains as California's first radon hot spot (Hobbs and Maeda, 1995). Research at the University of California at Santa Barbara by L.A. Kasper and E. Keller led them to estimate that approximately 4,000 homes in Santa Barbara County would have excess indoor radon levels because of their proximity to the Rincon Shale (Hobbs and Maeda, 1995). Later work by Hobbs and Maeda (1995) estimated that about 11,000 people in Santa Barbara County are being exposed to Rincon Shale related indoor radon levels exceeding 4.0 pCi/L.

The results of these investigations indicate that a deliberate geological exploration approach is more efficient than random sampling in identifying radon problem areas. This approach identifies geologic units more likely to cause radon problems and can be used to identify potential radon risks in undeveloped as well as developed areas. For these reasons, this approach was used by DMG in preparing detailed radon potential maps of Santa Barbara and Ventura counties for DHS.

Mapping Radon Potential Zones in Santa Barbara and Ventura Counties

These detailed potential radon maps prepared by DMG for DHS (Churchill 1995) are based on local geology, uranium (equivalent uranium) data from National Airborne Radiometric Reconnaissance (NARR) surveys (DOE, 1980; DOE, 1981), and available indoor-radon data. Three categories of radon potential zones are shown on the maps: high, moderate, and low. A map scale of 1:110,000 (1 inch equals 1.736 miles) was chosen because it delineates individual city blocks in urban areas but allows each map to fit within the computer plotter format size of 34 x 44 inches (a computer hardware limitation at the time of this project). Simplified, reduced scale versions of the Santa Barbara County and Ventura County radon potential maps are shown in Figures 5 and 6. All data analysis and mapping procedures, digitization of geologic and soil units, NARR flight-line data overlays, statistical categorization of radon zones, overlays of indoor radon measurement data, and production of the final maps were completed using a PC-computer-based Geographic Information System (GIS).

The locations of high, moderate, and low radon potential zone areas in these two counties were based on NARR equivalent uranium levels measured for geologic formation occurrences along flight-line paths (Figure 7). The basic premise is that geologic formations with higher equivalent uranium (eU) levels (eU defined in Figure 7) should have higher radon production. Consequently, more buildings on higher eU formations should have indoor-radon levels above 4.0 pCi/L.

Three steps were used to evaluate the high, moderate, and low radon potential zone areas using the NARR data for Santa Barbara and Ventura counties. The first step in determining the boundaries of the radon potential zones required finding which eU measurements along the flight lines were anomalously high. Anomalous values were defined as 5.0 ppm eU and greater, approximately twice the crustal uranium average. Defining anomalous

The maps in Figures 5 and 6 are not intended to determine which buildings have excessive indoor radon levels. Besides geology, local variability in soil permeability, weather and climatic conditions, building design and condition, and building usage also influence indoor radon levels. Consequently, building-specific radon levels can only be determined by indoor radon testing. No warranty as to actual radon levels at specific sites in Santa Barbara County (Figure 5) or Ventura County (Figure 6) is expressed or implied by this map or the accompanying report.

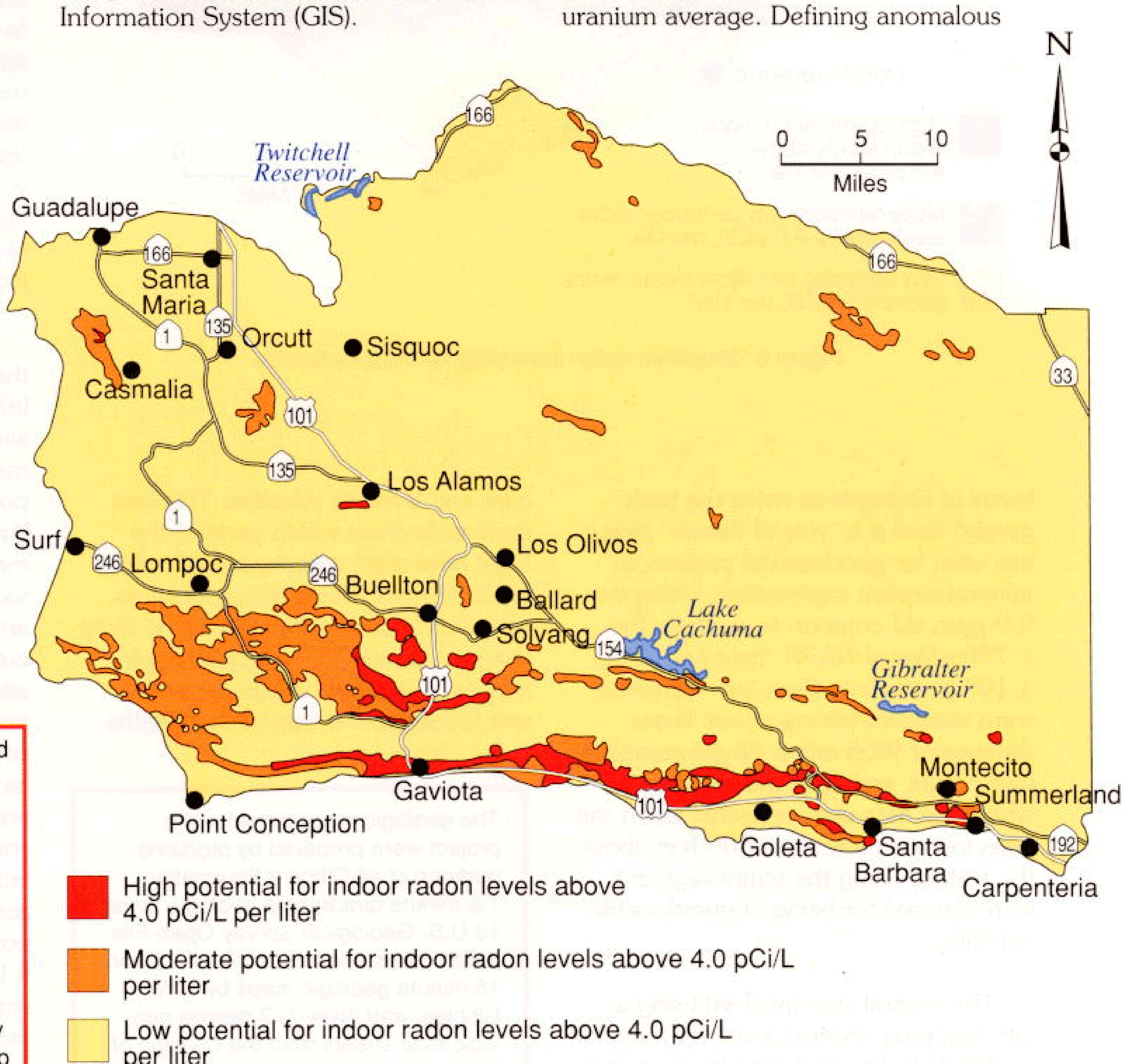

Figure 5. Simplified radon zone map for Santa Barbara County.

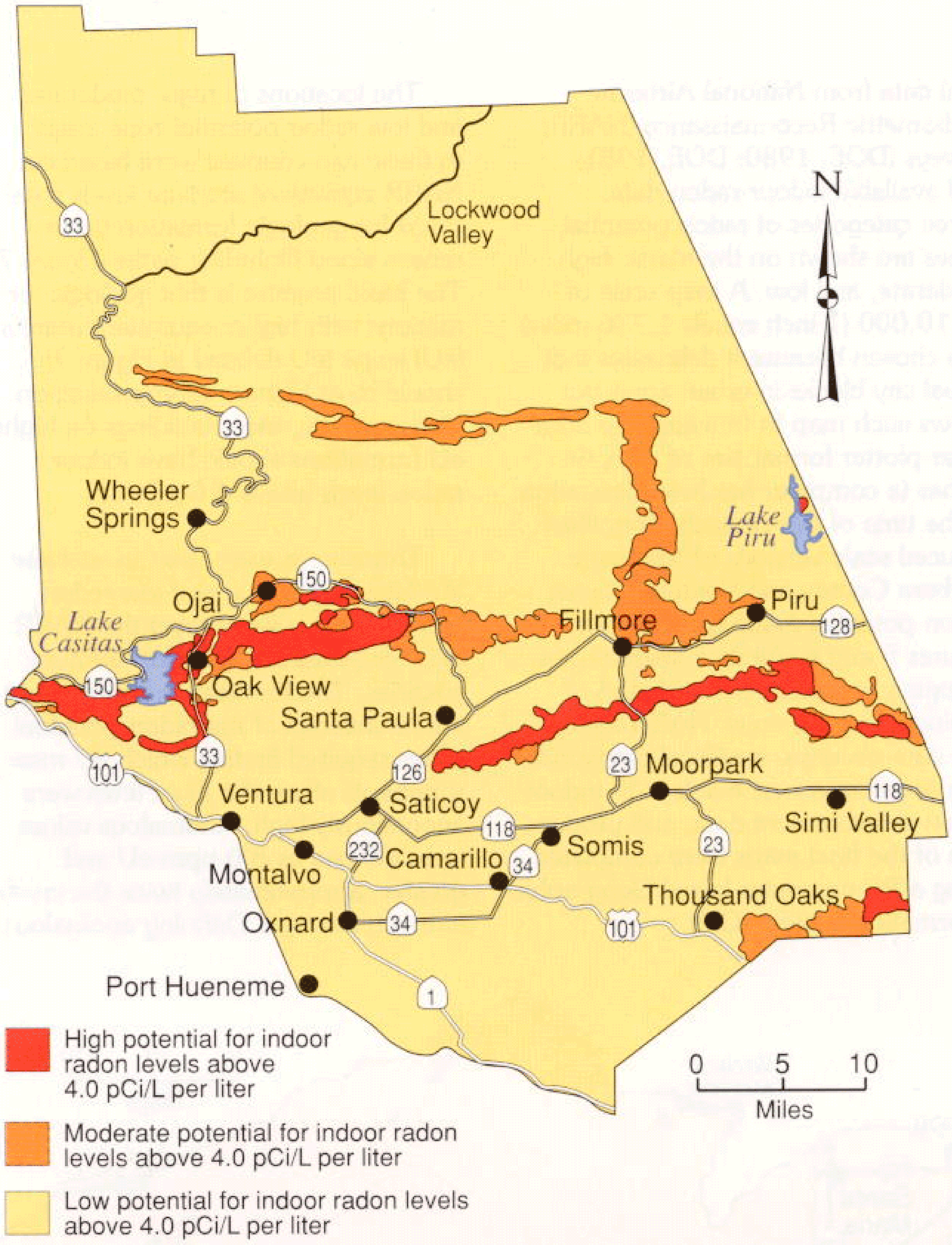

Figure 6. Simplified radon zone map for Ventura County.

of anomalous eU flight-line segments directly over that part of the geologic unit. This ratio was then expressed as a percentage anomaly value for each geologic unit occurrence along every flight-line path. Geologic units identified with this procedure as having higher incidence of anomalies are: the Rincon Shale, portions of the lower and upper units of the Monterey Formation (as mapped by Dibblee), alluvium derived from the Monterey or Rincon formations, and certain parts of the Pico Formation.

The percentage anomaly data could be reasonably divided into three subgroups of: 0 to 22 percent, 22 to 49 percent, and 49 to 100 percent. These data groups were used to define the different radon potential zones, low, moderate, and high, respectively. An exception in potential ranking was made for the Rincon Shale. All occurrences of Rincon Shale were classified as either having high potential (percentage anomalies above 49 percent) or moderate potential (in this case, moderate is defined as 0 to 49 percent). Spatial trends in radon potentials for occurrences of geologic units along flight-line paths were used to interpolate radon potentials for occurrences of geologic units between NARR flight lines.

The third and final step in mapping the radon potential zones was to establish radon zone boundaries. A 0.2 mile-wide buffer zone was drawn around the mapped boundaries of each high radon potential area, and a 0.1 mile-wide buffer zone was drawn around the mapped boundaries of each moderate radon potential area. The outer boundaries of these buffer zones become the outer boundaries of the high potential and moderate potential radon zones respectively. Areas outside these buffer zone boundaries were considered to have low radon potential. Where moderate potential and high potential buffer zones overlapped, the high potential buffer zone took precedence. The buffer zones were intended to: 1) account for potential indoor radon levels exceeding 4.0 pCi/L associated with alluvium and soil displaced from high and moderate radon potential geologic units by erosion; 2) help ensure complete inclusion of high and moderate radon potential

levels of elements as twice the background level is a "rule of thumb" practice used for geochemical projects in mineral deposit exploration. Using the 5.0 ppm eU criterion to evaluate the 1,700 miles of NARR flight-line grid, 1,107 anomalous flight-line segments were identified having a total linear distance of 98.6 miles. Single anomalous points, and anomalous segments where the data were collected when the detector was more than 600 feet above the surface along the entire segment, were ignored for being of questionable reliability.

The second step involved using a GIS mapping system to overlay a digital NARR flight-line grid map layer on digital geologic maps covering Santa Barbara and Ventura counties. This was done to find out which parts of the flight lines were associated with which geologic units. Once this association was determined, the length of the flight-line path directly overlying each geologic unit occurrence was measured and ratioed to the sum of the lengths

The geologic maps used for this project were prepared by digitizing portions of 44 Dibblee Foundation 7.5 minute quadrangle geologic maps, 10 U.S. Geological Survey Open-File report maps and unpublished 7.5 and 15 minute geologic maps by T.W. Dibblee, and three 1x2 degree geologic map sheets from the Division of Mines and Geology.

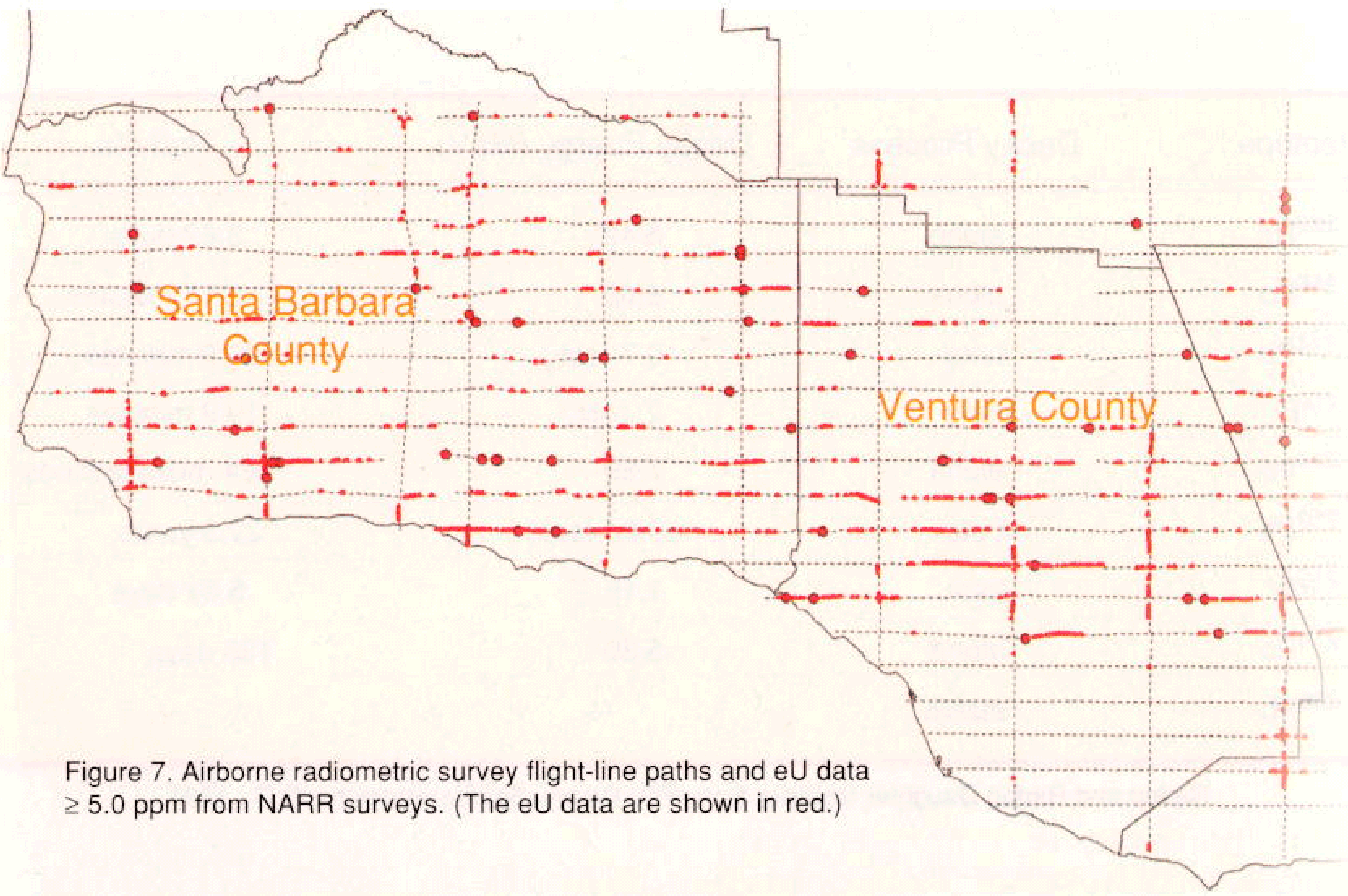

Figure 7. Airborne radiometric survey flight-line paths and eU data ≥ 5.0 ppm from NARR surveys. (The eU data are shown in red.)

The NARR data used in this project were originally collected as part of the Department of Energy's National Uranium Resource Evaluation (NURE) project and were collected during January and February 1980 (DOE, 1980; DOE, 1981).

Approximately 1,700 miles of NARR flight-lines were flown within Santa Barbara and Ventura counties in a grid pattern with east-west oriented lines about 3 miles apart and north-south "tie" lines about every 12 miles. A helicopter with a **gamma-ray** spectrometer, flying about 400 feet above the ground at 80-90 miles per hour was used to collect these data. The gamma-ray spectrometer detects gamma-ray energies unique to bismuth-214, one of the uranium-238 series decay products, and an immediate daughter element of radon-222. These relationships allow the uranium content of soil and rock at given locations along the flight-lines to be estimated.

The resultant estimated uranium values are called equivalent uranium (eU) because they are indirectly determined from the bismuth-214 data. Also, the close association of bismuth-214 and radon-222 in the uranium-238 decay series means that local eU levels will usually be positively correlated to local radon levels. Consequently, eU data can be used to predict high and low radon areas.

geologic units within the high and moderate radon potential zones wherever mapped formation boundaries are uncertain; and 3) include areas likely to have high and moderate radon potential geologic formations at shallow depths below alluvium within high and moderate radon potential areas. Creation of the buffer zones simplified the radon potential maps by consolidating many small detached zone occurrences into fewer and larger zones. An additional adjustment of buffer zone boundaries was made in the cities of Santa Barbara and Goleta to account for areas where Rincon Shale-derived soil and alluvium were displaced more than 0.2 miles down slope from Rincon Shale outcrops. One of these down slope areas has houses that are known to contain radon levels above 4.0 pCi/L (Hobbs and Maeda, 1995). These areas of displaced Rincon Shale-derived soil and alluvium are shown on the Radon Zone map for Santa Barbara County as moderate radon potential zones with boundaries derived from the Natural Resources Conservation Service's 7.5 minute soil maps for Santa Barbara and Goleta quadrangles (Shipman, 1980).

Upon the completion of the buffer zone additions and boundary adjustments, the radon potential zones were checked for validity using available short-term and long-term indoor radon data from several previous studies (Azzouz, 1990; Churchill and Youngs, 1993; Keller, University of California at Santa Barbara, written communication 1994; and Lui and others, 1991). Most houses above 4.0 pCi/L and two elementary schools with significant elevated radon problems (radon mitigation systems are now in place in these schools) were included within the high and moderate radon potential zones of the maps for Santa Barbara and Ventura counties. Consequently, no further modifications to radon zone boundaries were made based on existing house and school radon data. However, the locations of available indoor measurement data are not evenly distributed

Isotope	Decay Process	Decay Energy (MeV)	Half-life
^{222}Rn	alpha	5.49	3.82 days
^{218}Po	alpha	6.00	3.11 minutes
^{214}Pb	beta	0.7 (est.)	26.8 minutes
^{214}Bi	beta	2 (est.)	19.9 minutes
^{214}Po	alpha	7.69	164 microseconds
^{210}Pb	beta	0.04 (est.)	22.3 years
^{210}Bi	beta	1.16	5.01 days
^{210}Po	alpha	5.30	138 days
^{206}Pb	stable	—	—

Radon and Radon Daughter Isotopes from ^{238}U Decay. Source: Brookins, D.G., 1990.

over Santa Barbara and Ventura counties. Most of the data are from the city of Santa Barbara-Goleta urban area of Santa Barbara County and from low radon potential areas of Ventura County. If additional indoor radon data become available, future adjustments of radon potential zone boundaries may be necessary.

During the preparation of the Santa Barbara and Ventura counties radon potential maps, trends were noted in the percentage anomaly data suggesting that radon potentials for the Rincon Shale and the upper and lower Monterey Formation units vary over the two-county area. The percentage anomaly data suggest that the highest radon potential areas for these geologic formations are in the following 7.5 minute quadrangles.

- *Rincon Shale:* Dos Pueblos Canyon, Goleta, Santa Barbara, Carpenteria, White Ledge Peak, Pitas Point, Ventura, Solvang, Gaviota, and Ojai
- *Monterey Formation-lower unit:* Ojai and Santa Susana
- *Monterey Formation-upper unit:* Moorpark, Santa Paula, Calabasas, and Ojai.

These apparent spatial trends should be confirmed by additional research. The Pico Formation, not previously suspected to cause indoor radon problems, appears to have high radon potentials within the Santa Susana and Santa Paula Peak 7.5 minute quadrangles.

CONCLUSIONS

This work reconfirms previous findings that the Rincon Shale and the lower and upper Monterey Formation units (as mapped by Dibblee) are the most likely geologic units to cause excessive indoor radon levels in Santa Barbara and Ventura counties (Churchill, 1995). In total, the Rincon Shale and the Monterey Formation map units account for 39.2 percent of all flight-line eU anomalies identified in this study. The Rincon Shale contains 10.8 percent; the lower Monterey, 7.9 percent; and the upper Monterey, 20.5 percent. (Note that in areal extent the Rincon Shale covers only about 1.27 percent of the combined areas of Santa Barbara and Ventura counties.) Alluvium (map symbol Qa) within both counties contains 8.7 percent of the flight-line anomalies and many of these anomalies likely result from a Rincon Shale or Monterey Formation component. No other geologic formation within the two counties accounts for more than 3.2 percent of the flight-line anomalies

Based on the Radon Zone Maps for Santa Barbara and Ventura counties, priority areas for future indoor-radon testing are in and near the following: high and moderate potential zone areas west of Goleta in Santa Barbara County; high and moderate potential zone areas to the east and to the south of Ojai in Ventura County; and high and moderate potential zone areas in southeast and east-central Ventura County (Churchill, 1995).

Local variability of geology, soil, weather and climate, individual building characteristics and the habits of a building's inhabitants are all factors affecting indoor radon levels. These factors cannot be fully accounted for on a regional radon potential map. Therefore, the only way to find out the actual radon level in a building is by indoor radon testing of that building. The usefulness of these radon potential maps is to give local government health agencies, planning agencies, and private health organizations a better idea of where radon problems are most likely to occur within Santa Barbara and Ventura counties. With this information they can better target their testing, educational resources, and efforts where the needs are greatest.

Testing for Radon

Testing indoor radon levels in one's home is easy and inexpensive. The two types of detectors most commonly used for home testing are the short-term charcoal detector and the longer-term alpha-track detector (Photo page 176). Cost for either type of detector ranges from about $10 to $30 and includes laboratory analysis and a written report (*Consumer Reports*, 1995). These detection devices are passive, meaning that room air is not mechanically pumped through them. Short-term detectors use activated charcoal to adsorb radon from the air and are typically used for tests of 2 to 7 days duration. Normal procedure for short-term testing is to have the house's windows and doors closed during the test period, except for normal entry and exit by the occupants. At the end of the test period the detector is sealed and mailed to a lab for analysis. The long-term alpha-track detector consists of a piece of special plastic inside a container. It is typically used for tests of 91 days or more. For long-term testing the home is occupied in the normal manner rather than being closed. The special plastic is sensitive to damage by alpha particles emitted directly from radon that has diffused into the container from indoor air, and from polonium isotopes created from radon decaying within the container. At the end of the test period, the alpha-track detector is sent to a lab where the special plastic is removed and chemically treated to reveal any alpha-particle damage. The alpha-particle damage appears as microscopic linear tracks in the plastic and the long-term average radon level is determined from the number of tracks per unit area.

Radon levels in buildings can vary hour-by-hour and season-by-season as a function of weather, climate, closed or opened windows, heating, and air conditioning. Longer duration radon tests, therefore, provide a better indication of radon exposure than do shorter duration tests. A year-long alpha-track test will usually give a very good indication of how much radon exposure a building's occupants are receiving. In cases where radon testing is required for a real estate transaction, short-term testing is usually undertaken. The goal of the short-term test is to identify homes clearly above 4.0 pCi/L, so the house is closed and the detector is placed in the lowest occupied area, where the radon level should be the highest. For a valid test, the test device must be kept out of drafts and high humidity areas.

If a properly placed short-term device has a test result less than 4.0 pCi/L, it is likely that a year-long test under normal house conditions will also be less than 4.0 pCi/L (WRRTC, 1997). A long-term test is still recommended to verify long term levels will be less than 4.0pCi/L. If the short-term test result is above 4.0 pCi/L, one should confirm the result with a second short-term, closed-building test, placing the second detector in the same location as the first. It is recommended that mitigation steps be taken to decrease radon levels if the average of the two tests is 4.0 pCi/L or more. If not needed for a real estate transaction, the retest can be a long-term test (of 90 days or more; 1 year is recommended) under open-house conditions with the detector placed at the same location as the short-term device. Corrective measures to decrease radon levels would be based on the long-term result alone (WRRTC, 1997).

There are instances when a radon testing professional should be used. One example would be in a real estate transaction where a neutral third party is required. It is important that the testing professional is properly certified by DHS when contracting for radon testing services.

A Brief Summary of Radon Mitigation Practices

The EPA and private industry have developed radon mitigation techniques that can reliably reduce and maintain indoor radon levels below 4.0 pCi/L. The preferred mitigation is by active soil depressurization. In this approach, a system with a fan and a ventilation pipe is installed in the building to create a vacuum below the building's concrete slab or in the crawl space under an impermeable plastic sheet. Once installed the system creates a suction beneath the home or building that is greater than the vacuum applied to the soil from the house or building. This system is then able to collect and exhaust radon to the outside air before it can enter the building's air. The number of suction points required for a building depends upon the soil permeability beneath the building's slab and the number of intervening footings. Passive systems (no fan) can be incorporated into new buildings during construction. Activation of these passive systems can be easily done by adding a fan if testing discloses elevated radon levels (WRRTC, 1997) .

Typical costs for radon mitigation of a house range from $500 to $2,500, with the average cost of $1,200 (NCI, 1996). The additional cost for including a passive radon mitigation system at the time of home construction is usually significantly less than the costs for radon mitigation applied to an existing home. As in contracting for radon testing, radon mitigation work is best provided by certified radon mitigation contractors.

For additional information about home testing, contracting for services, and finding certified radon mitigation contractors call the DHS Radon Hotline at (800) 745-7236.

Short-term charcoal detector (a) and long-term alpha track detector (b). The larger canister is 4 inches across and 1-1/2 inches deep. *Photo by Max Flanery.*

ACKNOWLEDGMENTS

David Quinton, Department of Health Services, is thanked for reviewing preliminary versions of this paper, and his many helpful discussions with the author over the last 7 years. Discussions with Dr. William Hobbs (University of California, Santa Barbara), Dr. Donald Carlisle (Professor Emeritus, University of California, Los Angeles) and Helmut Ehrenspeck (Dibblee Foundation, Santa Barbara) as the author began the Santa Barbara and Ventura mapping project were very helpful. Dr. Edward Keller is thanked for allowing the author to examine his radon data for the Santa Barbara area. Finally, a number of DMG colleagues made many helpful suggestions for this paper, in particular Don Dupras, Bob Hill, and Trinda Bedrossian.

GLOSSARY

ALPHA PARTICLE: A relatively large radioactive decay particle equivalent to a helium nucleus with 100,000 times the ionizing potential of a gamma or x-ray; alpha particles can cause significant damage to lung tissue; penetration is less than other radioactive decay particles so cell damage is concentrated within narrow zones in tissue.

BETA PARTICLE: Particle given off during certain radioactive decay; an electron; penetration and tissue damage is intermediate as compared to other decay particles.

EMANATION: The ability of radon atoms to escape from their site of origin, usually from within mineral grains, into adjacent air or water-filled pore spaces in rock or soil.

GAMMA RAY: Short wave length electromagnetic radiation of nuclear origin from some radioactive decay processes. Similar to an x-ray in behavior and ability to damage tissue.

PICOCURIE (pCi): Unit of measure for the radioactivity of radon gas; a picocurie is one-trillionth of a curie; a curie is the number of disintegrations per minute (dpm) of gram of pure radium (equal to 2.22×10^{12} dmp).

RADON: A heavy radioactive gas produced in the decay series of Uranium-238, Uranium-235 and Thorium-232.

RADON DAUGHTER: One of several radioactive elements (polonium, lead, and bismuth) resulting from the radioactive decay of radon gas.

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